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THE DEVELOPMENT OF STRUCTURAL DESIGN AND THE SELECTION OF DESIGN PARAMETERS OF AERODYNAMIC SYSTEMS FOR DEORBITING UPPER-STAGE ROCKET LAUNCHER

The aerodynamic systems for upper-stage rocket launcher de-orbit have been analyzed. The feasibility and possibility of creating aerodynamic inflatable deorbit systems have been established. A mathematical model of upper-stage rocket launcher orbital motion has been developed. The aerodynamic deorbit system parameters for various configurations neglecting effects of space factors have been calculated. The effect of space factors on the aerodynamic deorbit system has been estimated. The effect of atomic oxygen and cosmic vacuum (sublimation) has been showed to lead to a decrease in shell thickness, while space debris causes an increase in consumption of working substance to inflate shell. The structural design has been selected and aerodynamic deorbit system parameters have been calculated with effect of space factors taken into account.

Keywords: upper-stage rocket launcher, space debris, aerodynamic deorbit system, and space factors.

Today, the near-space is filled with space debris. Fig. 1 [1] shows the growing dynamics of cataloged space debris (SD) fragments having a size over 10 cm, in near-earth orbits. Also, a steady increase in the amount of SD by 300 fragments per year has been reported, with low near-Earth orbits being the most littered region.

The main SD sources are spacecraft (SC), carrier rocket (CR) stages, and space missions (Fig. 2) [2].

In order to prevent the increase in the number of SD fragments, the Interagency Space Debris Coordination Committee has recommended to limit the orbital existence of space objects with a period of 25 years [3].

For spacecraft deorbiting from low near-Earth orbits both active and passive systems are used. The most common is deorbiting with the help of an active system, since such a method has been practiced in space research for the last 60 years. Its implementation requires SC orientation along the velocity vector, a deorbit burn, and, therefore, the operation of all SC service systems. However, it is known that the main causes for the SC failure is degradation of solar panels, loss of communication with SC, and other factors that in some cases make it impossible to use active systems for the deorbiting.

Unlike the active ones, the passive systems do not require SC orientation in space for its deorbiting. The most promising low near-Earth orbital systems are aerodynamic deorbiting systems and electrodynamic tether deorbiting systems [4, 5]. The disadvantages of tether systems include the problem of deploying a wire to required length (up to several kilometers) resulting in a signifi-

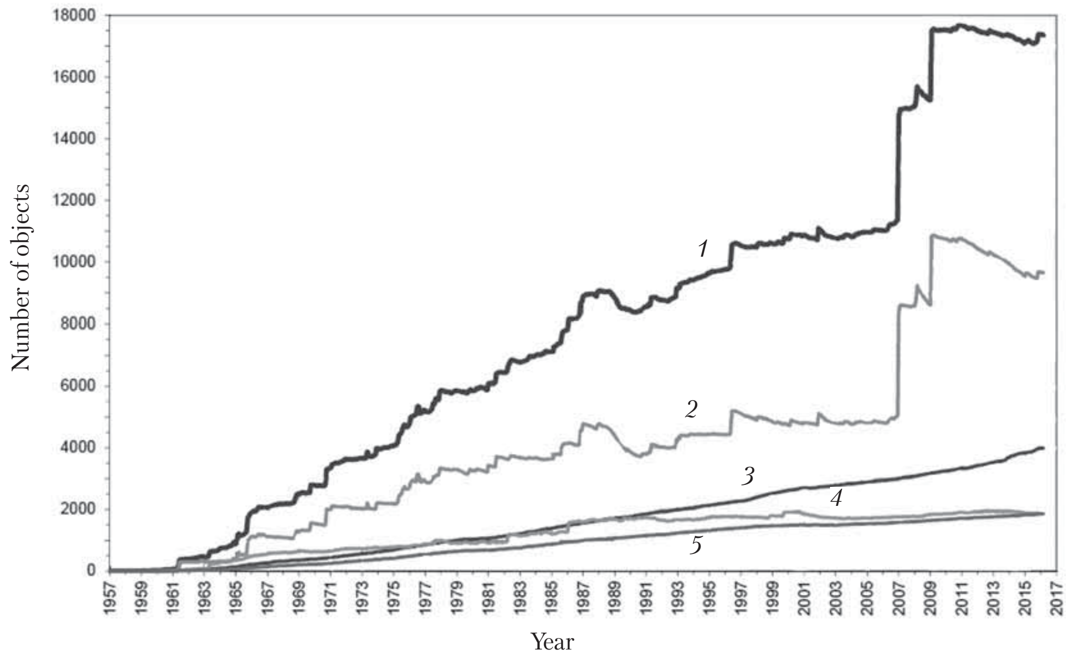


Fig. 1. Number of space debris in the near-Earth orbits [1] *1* — total number of objects; *2* — space debris fragments; *3* — spacecrafts; *4* — operation debris; *5* — boosters

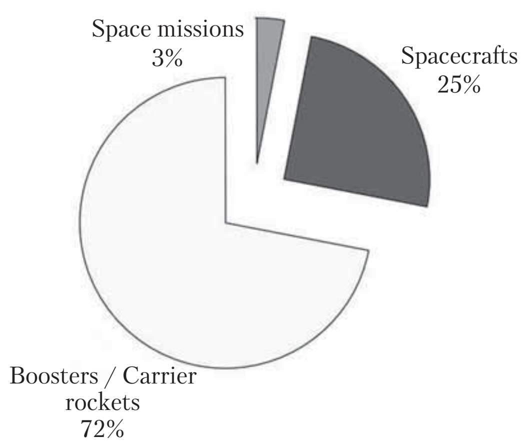


Fig. 2. Main sources of space debris [2]

cantly increased probability of tether obstruction, its insufficient tension and damage by SD.

The use of aerodynamic resistance forces of space objects to perform their basic functions [6—9] and inflatable space aerodynamic systems [10—15] has enabled to create aerodynamic systems for spacecraft deorbiting (SCADS) [16—27]. An example of this is a successful experiment on the deployment of SCADS in the form of a square sail (NANOSAIL-D), when a 4 kg nanosatellite was deorbited in 240 days, which confirmed the system feasibility.

DESIGN OF CONFIGURATIONS AND PARAMETERS OF BOOSTER ROCKET DEORBITING AERODYNAMIC SYSTEM

As mentioned above, one of the main sources of SD is carrier rocket stages. When designing the upper rocket carrier, *Pivdenne* Design Office faced a need to create an aerodynamic deorbiting system (ADS). Two symmetrical zones were allocated for placing ADS on RC board (Fig. 3).

To design a configuration, a solid-state model of the CR stage was created with allocated volume adapted (Fig. 4).

The technical parameters of the CR stage are as follows:

weight, kg	2140
orbit height, km	600—1000
eccentricity of the orbit	0.0004

The input data for ADS design are as follows:

- the system weight shall not exceed 45 kg;
- the term of orbital existence of CR stage with ADS: 25 years.

A method for reducing the ballistic lifetime of space objects in near-Earth orbits and a device for its implementation has been proposed to adapt existing ADS for its use on the upper CR stages [28].

The device operates as follows. For deorbiting the SC, using the element 2, the aerodynamic element (AE) 3 moves forward (Fig. 5, *a*) and the space object starts leaving orbit. As soon as AE fails, it is disconnected from the space object (Fig. 5, *b*). The causes of its damage are the loss of shell material thickness under the influence of space vacuum and atomic oxygen, as well as the loss of the shell integrity, which occurs under the action of space debris. As the SC descends to the altitude acceptable for AE deployment, a new AE element is deployed, with the SC continuing deorbiting (Fig. 5, *c*). If this AE also fails, it is disconnected in the same way as the previous AE (Fig. 5, *g*, *d*). All AEs can be disconnected from SC, except for the last one that, together with SC, reaches the dense atmospheric strata (Fig. 5, *e*). As a result, the volume and mass required to use a single shell on SC board decrease, whereas the ADS operation reliability increases.

ANALYSIS OF SPACE FACTORS EFFECT ON ADS

The ADS is assumed to be effected by the following space factors:

- Space vacuum (sublimation);
- Atomic oxygen;
- SD.

The long-term action of vacuum leads to loss of matter, mainly, as a result of sublimation. The rate of polymeric material thickness change under the sublimation effect is calculated by the formula [29]:

$$\frac{d\Delta_1}{dt} = S_{\text{П}} \frac{P_{\text{ПНГ}i}}{\rho_{\text{М}}} \sqrt{\frac{\mu_{\text{ПМ}}}{2 \cdot N_{\text{А}} \cdot k_{\text{Б}} \cdot T_{\text{ППМ}}}}, \qquad (1)$$

where $S_{\text{П}}$ is ADS surface area; $P_{\text{ПНГ}i}$ is saturated gas pressure of sublimed material defined by the formula [29]:

$$P_{\text{ПНГ}i} = 0.0007181 \cdot e^{\left(A - \frac{B}{T_{\text{ППМ}}}\right)}, \qquad (2)$$

where A, B are coefficients that according to [30] are assumed to be equal to $A = 3$, $B = 3000$; $\rho_{\text{М}}$ is sublimed matter density; $\mu_{\text{ПМ}}$ is molecular weight of film material, for PM-A polyimide $\mu_{\text{ПМ}} = 0.12212$ kg/mole [31]; $N_{\text{А}}$ is the Avogadro number, $N_{\text{А}} = 6.022 \cdot 10^{23}$ mole^{-1}; $k_{\text{Б}}$ is the Boltzmann constant, $k_{\text{Б}} = 1.38 \cdot 10^{-23}$ J/K; $T_{\text{ППМ}}$ is surface temperature of film material (FM).

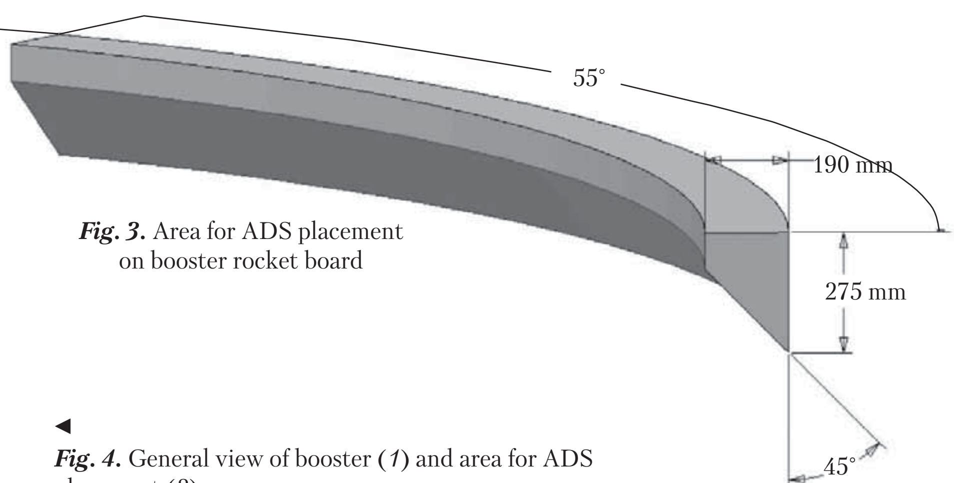
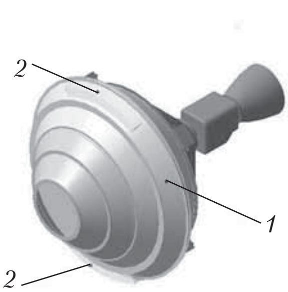


Fig. 3. Area for ADS placement on booster rocket board



◄ ***Fig. 4.*** General view of booster (*1*) and area for ADS placement (*2*)

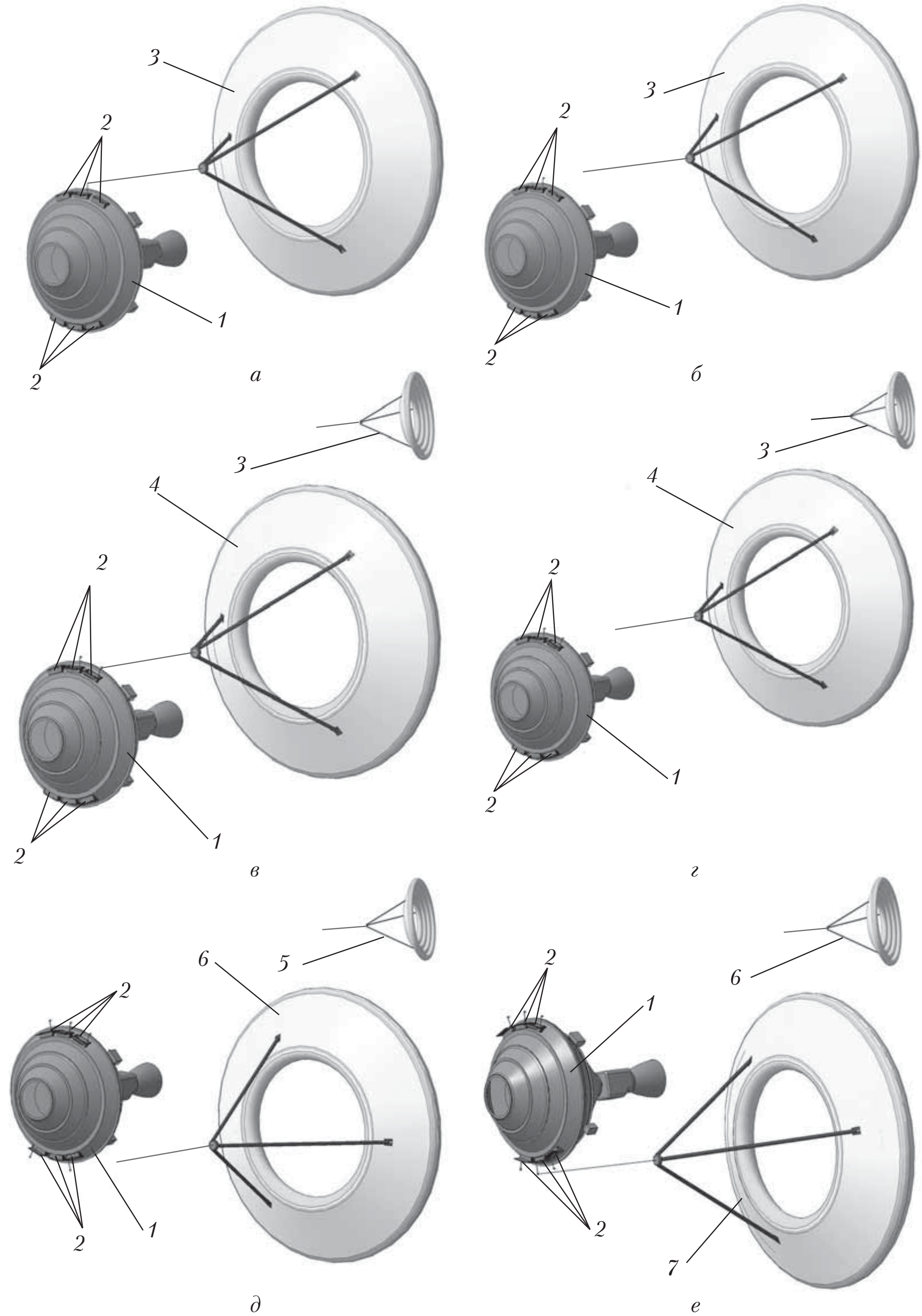


Fig. 5. External view of ADS: *a* — initial position; *b* — the first AE disconnection; *c*— launch of the next AE; *d* — repeated disconnection of AE; *e* — the next AE disconnection; *f* — launch of AE: *1* — space object; *2* — element to fasten ADS to space object; *3*–*6* — aerodynamic element

In near-Earth orbits, the factor that determines changes in the chemical, thermo-optical, and mechanical properties of polymers is high-speed atomic oxygen fluxes. The change in film thickness under the influence of atomic oxygen is determined by the formula [32]:

$$\frac{d\Delta_1}{dt} = R_E \cdot \Phi_{AK}, \tag{3}$$

where R_E is film mass loss factor defined by the formula [32]:

$$R_E = 10^{-30} \cdot (9.5 - 8.3\, e^{0{,}15\,(1-\gamma)}); \tag{4}$$

γ is erosion coefficient for PM-A polyimide, $\gamma = 2.3$; Φ_{AK} is atomic oxygen flux.

The effect of SD on ADS is estimated by the following algorithm:

1) To determine minimum size $d_{\min}$ of SDF capable of damaging the shell of thickness δ;

2) To calculate collision frequency of ADS shell and SDF;

3) To estimate pressure drop inside ADS shell.

Minimum size $d_{\min}$, of SD fragment capable of damaging the shell of thickness δ is calculated by the ballistic equation [33]:

$$d_{\min} = (0.106022 \cdot t \cdot H_B^{1/4} \cdot \sqrt{\rho_t/\rho_p} \cdot (c/V)^{2/3})^{0{,}947368}; \tag{5}$$

where $d_{\min}$ is SDF diameter; $H_B^{1/4}$ is Brinell hardness of target material; ρ_t, ρ_p are SDF and film material densities; c is sound speed in SDF material (for aluminum $c = 5.1$ km/s); V is SDF velocity (average velocity $V \approx 10$ km/s).

Based on obtained $d_{\min}$ the collision frequency of ADS shell and SDF is calculated [34]:

$$N = S_\Pi \cdot Q\,(d_i); \tag{6}$$

$$d_{\min} \le d_i \le d_{\min}, \tag{7}$$

where S_Π is ADS surface area; $Q\,(d_i)$ is average flux of SDF with a diameter d_i at a given altitude h calculated using MASTER-2009 model [54]; $d_{\min}$, $d_{\max}$, are minimum and maximum SDF sizes for calculations using MASTER-2009.

Further, pressure drop inside ADS shell as a result of SDF action during t_L is estimated. Using d_i, the rate V_O of formation of holes having an area of S_O in the shell for time t_L is calculated as:

$$V_O = S_O \cdot N, \tag{8}$$

where S_O is area of holes in the shell as a result of collision with SDF calculated as:

$$S_O = \sum_{i=1}^{n} \frac{\pi d_i^2}{4}, \tag{9}$$

where d_i is SDF diameter.

Mass gas flux Δ_3 through the hole of area S_O is determined by the formula [55]:

$$\Delta_3 = \frac{1}{\sqrt{2\pi R}} \left(\frac{p_1}{\sqrt{T_1}} - \frac{p_2}{\sqrt{T_2}} \right) S_o, \tag{10}$$

where p_1, p_2 are gas pressure inside the shell and exosphere pressure, respectively; T_1, T_2 are of gas inside the shell and exosphere temperature, respectively; R is universal gas constant, $R = 8.3144621$ m^2 · kg/s^2 · K · mole.

ADS stops operation if $p_1/\sqrt{T_1} = p_2/\sqrt{T_2}$ and $G \to 0$.

ADS PARAMETER OPTIMIZATION

Since the main task of optimization is to minimize ADS weight, it is necessary to set up the criterion:

$$m_{ACY} \to \min. \tag{11}$$

ADS weight parameters depend on design parameters of its elements which have to effectively deorbit the booster rocket. Therefore, all ADS elements put limitations of ADS weight depending on effectiveness criterion that can be written as inequality:

$$t_{CAC} \ge t_L, \tag{12}$$

where t_{CAC} is ADS active lifetime under the influence of space factors; t_L is orbital life of booster rocket with ADS.

The input data for choosing the optimal configuration are as follows:

- booster rocket weight is 2150 kg;
- Orbit height is 600 km; 700 km; 800 km; 900 km; 1000 km;

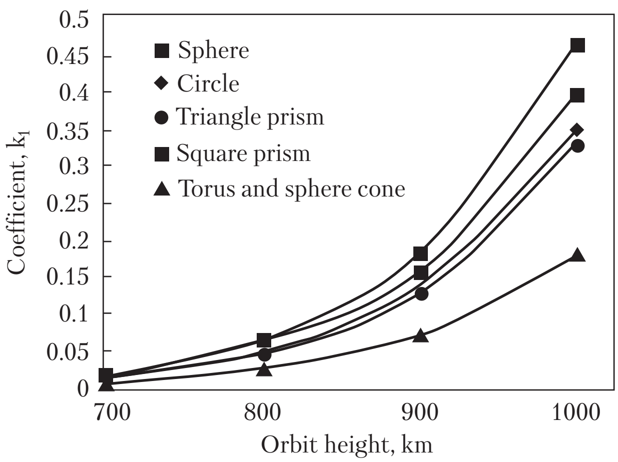


Fig. 6. Results of optimal configuration selection

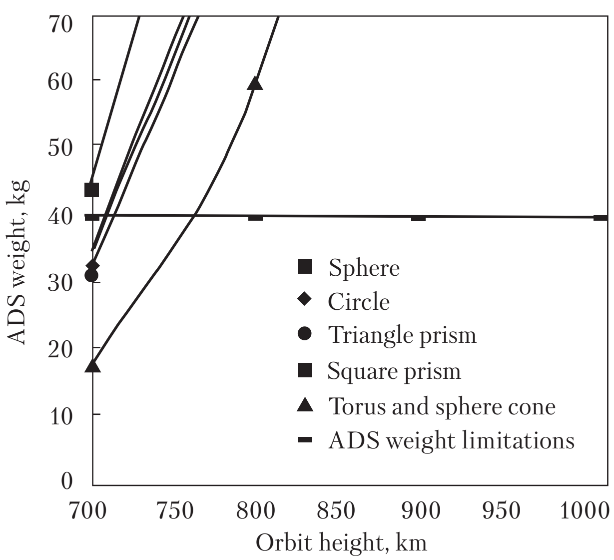


Fig. 7. Determination of ADS effective use limits

- ADS configurations: *Sphere, Circle, Triangle Prism, Square Prism, and Torus and Sphere Cone*.

The ADS configuration parameters are as follows:

- ADS weight;
- ADS aerodynamic element weight;
- Pressurizing system weight;
- Storage system weight.

The requirements for ADS are as follows:

- ADS weight $\leq$ 40 kg;
- Orbital lifetime is 25 years.

Simulation has been done for the input data and ADS weight for various configurations has been calculated. The ADS parameter optimization by the criteria is:

$$F_{m_{ACY}} = f\,(m_{AE}\,,\Delta_1, \Delta_2, m_{CX}, \Delta_3) \rightarrow \min \left| \frac{t_{CAC} \geq t_L}{m_{ACY} \leq m_{ACY}^{\partial on}} \right. . \tag{13}$$

The optimization results are given in Figs. 6 and 7.

Figs. 6 and 7 show that according to the criterion (12), the most effective is *Torus and Sphere Cone* configuration.

DETERMINATION OF ADS APPLICATION LIMITS

For estimating limits of AS application for booster rocket deorbiting the following input data are assumed:

- booster rocket weight m_{CT};
- area of middle booster rocket cross section S_M;
- booster rocket apogee height h_A;
- orbit eccentricity e;
- ballistic lifetime t_L.

The design parameters are determined using methodological approaches showed in the second section of this research. Analysis of ADS application limits are based on assumptions:

- ADS has a spherical shape, i.e. ADS based on single shells is used;
- ADS weight is determined by weights of aerodynamic element, pressurizing system, and storage system;
- ADS weight shall be less or equal to weight of working substance required for booster deorbiting;
- ADS weight shall be less or equal to weight allotted for ADS on the booster;
- The effect of space factors has been taken into consideration.

The mathematical statement for choosing ADS parameters is to minimize the ADS weight. In this case, the optimization criterion formula is fair:

$$m_{CT} = f\,(t_L, m_{CT}, S_M, m_{AE}, m_{CH}, m_{CX}, \Delta_1, \Delta_2, \Delta_3) \rightarrow$$

$$\rightarrow \min \left| \frac{m_{ACB} \leq m_{\Pi}}{m_{ABC} \leq m} \right. , \tag{14}$$

where m_{ACB} is ADS weight; m_{AE} is ADS aerodynamic element weight; m_{CH} is ADS pressurizing system weight; m_{C3} is weight of system for ADS keeping on booster board; m_{Π} is weight of fuel required for booster deorbiting as calculated by the formula

$$m_{\Pi} = m_{CT}\left(1 - e^{\left(-\frac{\Delta V}{w_u}\right)}\right), \qquad (15)$$

where m_{CT} is booster weight; ΔV is required velocity margin required for booster deorbiting; Δ_1, Δ_2, Δ_3 are coefficients to take into account the effect of space factors: space vacuum, atomic oxygen, and space debris, respectively.

For comparative analysis a liquid-fueled jet propulsion system is used as active system for deorbiting waste SC.

Effectiveness of propulsion system use for deorbiting has been estimated by the following algorithm:

1) determination of SC ballistic lifetime;

2) determination of necessity of deorbiting maneuver;

3) calculation of final orbit parameters depending on given SC ballistic lifetime;

4) calculation of increase in velocity required for transition for final orbit;

5) calculation of fuel weight required for booster deorbiting.

To determine the application limits it is necessary to compare ADS weight with fuel weight required for deorbiting (Fig. 8).

Analysis of obtained results (Fig. 8) has showed that ADS is feasible to be used for deorbiting the booster rockets from orbits with a higher under ≈ 780 km.

METHODS FOR ADS PARAMETER SELECTION

To solve the problem of choosing the ADS parameters, a method has been developed that enables to obtain information on the system parameters with ADS size limitations and space factor

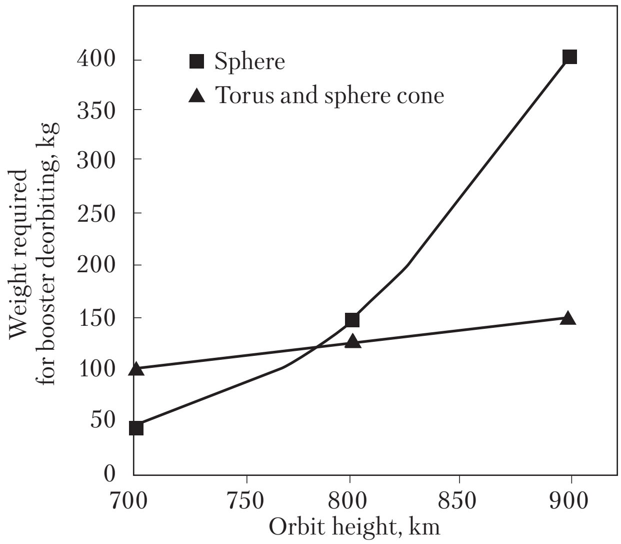


Fig. 8. Comparison of ADS weight with rocket fuel weight required for booster rocket deorbiting

effect taken into account at different stages of the development of technical proposal.

In the first approximation, the limits of ADS application are defined. The following assumptions are used:

- ADS is spherical;
- ADS weight is determined by weight of aerodynamic element (AE), while weights of pressurizing, storage, and deployment systems are not taken into account;
- the ADS weight must be less than or equal to the mass of fuel required for booster rocket deorbiting maneuver;
- the effect of space factors is not taken into account.

The mathematical formulation of the choice of ADS parameters in this case is as follows:

$$m_{CT} = f\,(t_L, m_{CT}, S_M, m_{AE}) \rightarrow \min|k_1 \leq k_2, \qquad (16)$$

where t_L is ballistic lifetime of booster rocket with ADS; m_{CT} is booster rocket weight; S_M is area of middle ADS cross section as defined by formula [5]:

$$S_M = \frac{2m_{CT}\sqrt{\dfrac{a}{\mu}}\cdot X\,(e, z)}{t_L\, 3\, \rho_{pe}\, C_X}\,, \qquad (17)$$

$$X(e, z) = \frac{3 \cdot e \cdot \exp(z)}{4 I_0(z) + 8eI_1(z)} \left\{ 1 + \frac{7e}{6} + \frac{5e^2}{16} + \frac{1}{2z} \times \right.$$

$$\left. \times 1 + \left(\frac{11e}{12} + \frac{3}{4z} + \frac{3}{4z^2} \right) \right\}. \quad (18)$$

C_X is aerodynamic resistance coefficient; in the case of undirected SC motion it is assumed that $C_X = 2.2$; ρ_{pe} is atmospheric density in orbit perigee; $I_k(z)$ are Bessel functions of order $k = 0$ and 1 and argument $z = ae/H_{\rho,pe}$; e is orbit eccentricity; μ is Earth gravitational parameter; a is major semi-axis; $H_{\rho,pe}$ is height of dense atmosphere; m_{AE} is ADS aerodynamic element weight; k_1 is criterion of propulsion system effectiveness

$$k_1 = \frac{m_T}{m_{KA}}, \quad (19)$$

m_T is weight of working substance required for booster rocket deorbiting maneuver

$$m_T = m_{KA} \left(1 - e^{\left(-\frac{\Delta V}{w_u}\right)} \right), \quad (20)$$

ΔV is increase in velocity required for SC deorbiting maneuver; it is determined by formula [5]:

$$\Delta V = \sqrt{\frac{2\mu}{r_a}} \left(\sqrt{\frac{r_n + \Delta r_n}{r_a + r_n + \Delta r_n}} - \sqrt{\frac{r_n}{r_a + r_n}} \right), \quad (21)$$

r_a is radius vector of booster rocket in the orbit apogee; r_n is radius vector of booster rocket in orbit perigee; Δr_n is a height to lower perigee; w_u is working substance outflow velocity; k_2 is criterion for assessment of ADS effectiveness

$$k_2 = \frac{m_{ACY}}{m_{KA}}, \quad (22)$$

m_{ACY} is ADS weight; at the given stage it is defined by AE weight calculated by the formula:

$$m_{ACY} = 1.27 \sqrt{S_M} \cdot \delta_{MHE} \cdot \rho_{MHE}, \quad (23)$$

δ_{MHE} is thickness of pneumatic element material; ρ_{MHE} is density of pneumatic element material.

In the 2nd approximation ADS parameters are calculated taking into consideration the weights of storage and pressurizing systems and feasibility analysis of ADS use is made. At this stage, ADS is assumed spherically configured. Its configuration has to meet limitations on ADS structural element dimensions and to have a minimum weight m_{ACY}.

In this case the ADS configuration is limited by the following:

- AE diameter d_{AE} shall be less than or equal to the permissible shell diameter d_{AE}, in the given case ADS spherical element is used as aerodynamic element;
- length of inflatable mast (IM) l_{HM} shall be less than or equal to the permissible length l_{HM}.

At this stage of ADS parameter selection, the space factor effect is neglected. The mathematical formulation is as follows:

$$V = f(V_{AE}, V_{CX}, V_{CH}) \rightarrow \min, \quad (24)$$

where m_{CX} is ADS storage system weight. Let us assume that the ADS storage system on SC board is shaped as cube with its weigh m_{CX} defined by the formula:

$$m_{CX} = 6 \left(\sqrt[3]{V_{MHE} + V_{CH}}\right)^2 \cdot \delta_{MCX} \cdot \rho_{MCX}, \quad (25)$$

where δ_{MCX} is thickness of storage system material; in this case $\delta_{MCX} = 5 \cdot 10^{-4}$ m; ρ_{MCX} is density of storage system material. The storage system is made of TD 33 aluminum alloy having a density $\rho_{MCX} = 2700$ kg/m^3; V_{MHE} is volume of pneumatic element material; V_{CX} is volume of pressurizing system; m_{CH} is weight of pressurizing system.

In the third approximation, ADS parameters are calculated for various configurations, with size limitations taken into account. At this stage, ADS parameters are defined more precisely with space factor (space vacuum, solar radiation, atomic oxygen, and SD) effect taken into consideration. The mathematical formulation for ADS parametrization is as follows:

$$m_{ACY} = f(m_{AE}, \Delta_1, \Delta_2, m_{CX}, m_{CP}, m_{CH}, \Delta_3) \rightarrow$$

$$\rightarrow \min \left| \frac{d_{AE} \le d_{AE}^{\partial on}}{l_{HM} \le l_{HM}^{\partial on}} \right., \quad (26)$$

where Δ_1 is space vacuum effect (polymeric material sublimation) coefficient; Δ_2 is atomic oxygen effect coefficient; Δ_3 is SD effect coefficient.

To calculate the model input parameters for taking into account the space factor effect, the system of equations shall be solved [5]:

$$\left.\begin{aligned}
\frac{da}{dt} &= \sqrt{\frac{a}{\mu}} - \frac{2a}{\sqrt{1-e^2}}\,(e\sin\vartheta\cdot S + (1+e\cos)T),\\
\frac{de}{dt} &= \sqrt{\frac{a}{\mu}}\,\sqrt{1-e^2}\left(\sin\vartheta S + \frac{e+2\cos\vartheta + e\cos^2\vartheta}{1+e\cos\vartheta}\,T\right),\\
\frac{di}{dt} &= \sqrt{\frac{a}{\mu}}\,\frac{\sqrt{1-e^2}}{1+e\cos f}\,\cos(\omega+\vartheta)W,\\
\frac{d\Omega}{dt} &= \sqrt{\frac{a}{\mu}}\,\frac{\sqrt{1-e^2}}{1+e\cos f}\,\frac{\sin(\omega+\vartheta)}{\sin i}W,\\
\frac{d\omega}{dt} &= \sqrt{\frac{a}{\mu}}\,\frac{\sqrt{1-e^2}}{e} - \left(\cos\vartheta S + \frac{2+e\cos\vartheta}{1+e\cos}\,sin\vartheta T\right) - \cos i\frac{d\Omega}{dt}\\
\frac{d\omega}{dt} &= \mathrm{n} + \frac{1-e^2}{e}\left[\left(\cos\vartheta - \frac{2e\cos\vartheta}{1+e\cos\vartheta}\right)S - \frac{2+e\cos\vartheta}{1+e\cos\vartheta}\,sin\vartheta T\right],
\end{aligned}\right\} \quad (27)$$

The system of equations (27) is integrated using the Adams-Bashforth method with an integration step of 1 day.

Having solved the system of equations, the time for which the booster rocket with ADS onboard downs by a height of one stratum (50 km) for which coefficients Δ_1, Δ_2 , Δ_3. are calculated is determined. As the booster rocket reaches the next strata, the parameters shall be recalculated. The iterative procedure for calculation of coefficients Δ_1, Δ_2 , Δ_3 shall continue until the booster rocket reaches a critical height of 150 km, i.e. the endoatmospheric boundary. As soon as orbit height of 150 km is reached the iteration procedure stops. At the same time, the thickness AE material at which AE can operate for a given orbit lifetime is calculated.

CONCLUSIONS AND RECOMMENDATIONS

As a result of aerodynamic system study, the creation of aerodynamic pressurizing systems for deorbiting has been found feasible. Aerodynamic deorbiting systems have been classified; configuration and parameters of ADS for booster rocket deorbiting have been chosen. The ADS configuration includes aerodynamic element, pressurizing subsystem, and aerodynamic subsystem for ADS storage on booster rocket board.

A mathematical model of effect of space factors on ADS has been developed; The atomic oxygen and space vacuum (sublimation) effects have been showed to cause a decrease in shell thickness, while SD effect leads to increase in consumption of working substance for the pressurizing the shell. ADS parameters have been calculated for a service life of 25 years with space factor effect taken into consideration. Tetrahedron has been found the optimal configuration in terms of expended weight. For adapting the existing ADS to their use on booster rockets a method for reducing ballistic lifetime on the near-Earth orbits and a device for decreasing volume of ADS on booster rocket board have been proposed.

Limits of ADS application have been determined and expediency of ADS use for booster rocket deorbiting at a height under 780 km has been justified. ADS parameters have been optimized for various configurations, with Torus and Sphere Cone being the most optimal configuration.

The results have been implemented at Pivdenne Design Office when choosing the parameters of ADS for Cyclone 4 booster rocket deorbiting.

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РОЗРОБКА КОНСТРУКТИВНОЇ СХЕМИ ТА ВИБІР ПРОЕКТНИХ ПАРАМЕТРІВ АЕРОДИНАМІЧНОЇ СИСТЕМИ ВІДВЕДЕННЯ З ОРБІТИ РОЗГІННИХ СТУПЕНІВ РАКЕТ-НОСІЇВ

Наведено аналіз та класифікацію аеродинамічних систем відведення з орбіти розгінних ступенів ракет-носіїв і визначено технічну реалізованість і можливість створення аеродинамічних надувних систем для відведення. Складено математичну модель орбітального руху розгінного ступеня ракети-носія. Проведено розрахунок параметрів аеродинамічних систем відведення різних конфігурацій без урахування впливу факторів космічного простору. Оцінено вплив факторів космічного простору на аеродинамічну систему відведення та показано, що вплив атомарного кисню й космічного вакууму (сублімації) призводить до зменшення товщини оболонки аеродинамічного елементу системи, а вплив фрагментів космічного сміття до збільшення витрат робочої речовини для надування оболонки аеродинамічного елементу системи. Обрано конструктивну схему та проведено розрахунок параметрів аеродинамічної системи відведення з урахуванням впливу факторів космічного простору.

Ключові слова: розгінна ступінь ракети-носія, космічне сміття, аеродинамічна система відведення, фактори космічного простору.

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РАЗРАБОТКА КОНСТРУКТИВНОЙ СХЕМЫ И ВЫБОР ПРОЕКТНЫХ ПАРАМЕТРОВ АЭРОДИНАМИЧЕСКОЙ СИСТЕМЫ УВОДА С ОРБИТЫ РАЗГОННЫХ СТУПЕНЕЙ РАКЕТ-НОСИТЕЛЕЙ

Представлен анализ и классификация аэродинамических систем увода с орбиты разгонных ступеней ракет-носителей и определена техническая реализуемость и возможность создания аэродинамических наддувных систем для увода. Составлена математическая модель орбитального движения разгонной ступени ракеты-носителя. Проведен расчет параметров аэродинамических систем увода различных конфигураций без учета влияния факторов космического пространства. Проведена оценка влияния факторов космического пространства на аэродинамическую систему увода, показано, что влияние атомарного кислорода и космического вакуума (сублимации) ведет к уменьшению толщины оболочки, а влияние фрагментов космического мусора — к увеличению расходов рабочего вещества для наддува оболочки. Выбрана конструктивная схема и проведен расчет параметров аэродинамической системы увода с учетом влияния факторов космического пространства.

Ключевые слова: разгонная ступень ракеты-носителя, космический мусор, аэродинамическая система увода, факторы космического пространства.